CMS Calibration Strategy
for Jet/MET

Shuichi Kunori
U. of Maryland
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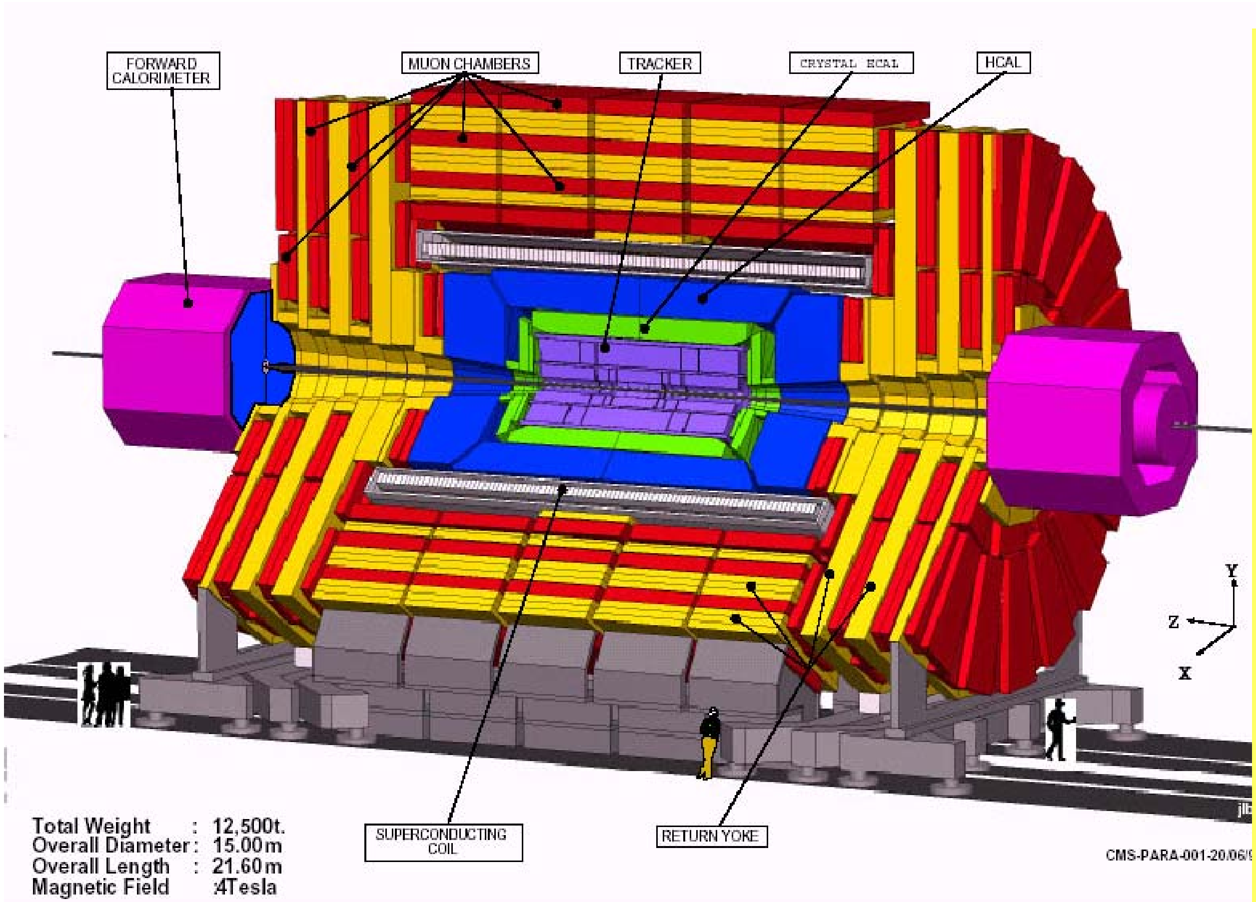
CMS and LHC
HCAL calibration
Jet/MET Calibration
Conclusion

CMS Detector



Tracker
- All silicon
- $|\eta|<2.4$

ECAL
- PbWO4 crystals
- e/h ~ 1.60
- $|\eta|<3.0$

HCAL (barrel/endcap)
- Scint-tile & brass sampling
- e/h ~ 1.39
- $|\eta|<3.0$

– 4 Tesla field –

HCAL (fwd)
- Quartz-fiber & iron
- $3.0<|\eta|<5.0$

Segmentation $\Delta\eta$ x $\Delta\phi$
- ECAL (80Kch) : 0.017 x 0.017 (larger in higher η)
- HCAL (9Kch) : 0.087 x 0.087 (larger in higher η)
- -- no longitudinal segmentation in ECAL and HCAL.

LHC and Pile-up

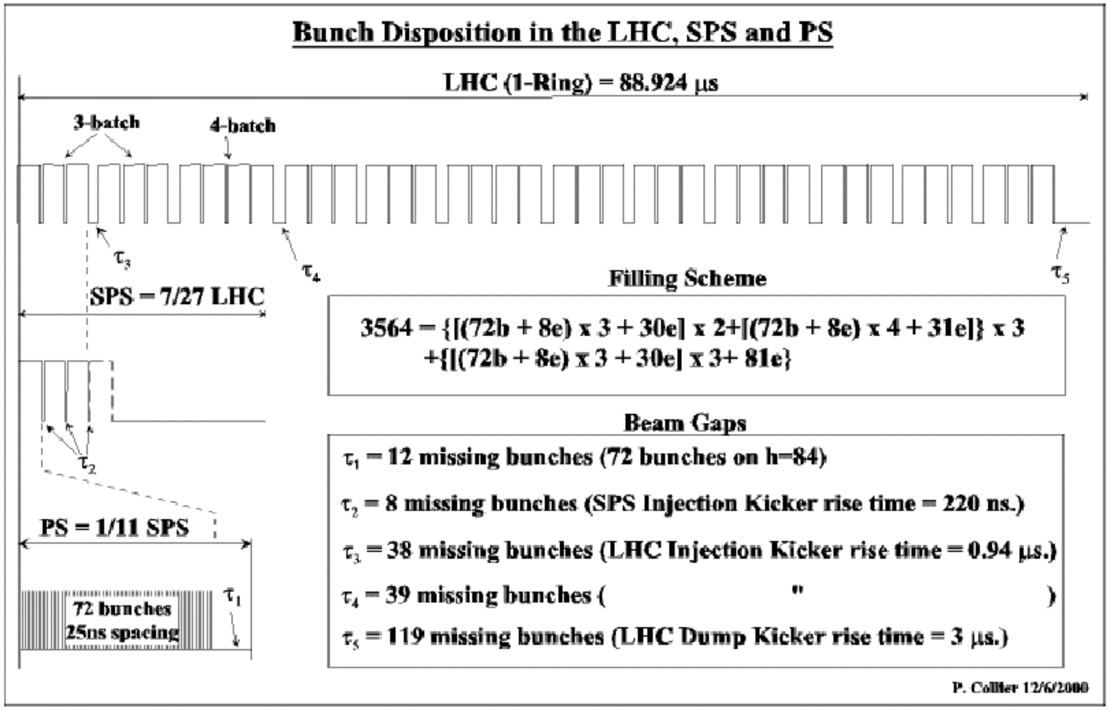
Proton + proton 7+7 TeV

Low Luminosity (2007) $L = 2 \times 10^{33}\ cm^{-2}\ s^{-1}$

High Luminosity (?) $L = 1 \times 10^{34}\ cm^{-2}\ s^{-1}$

<17.3> min. bias/beam crossing, $<E_T> \sim 17 GeV/(\eta x \phi)$

LHC beam structure



LHC machine parameters

bunch spacing 25nsec

bunches
- total 3564
- filled 2808 (79%)

structure 72b + 8e

Lumi lifetime ~15 hours

σ_Z(IP) ~ 6cm

Calibration: Three Levels

Inter channel calibration / HCAL Energy Scale

- **ADC counts → initial GeV in HCAL (& ECAL)**
  - Channel by channel correction for
    - **Scintillation and Cerenkov light collection**
    - **photo detectors & electronics, etc.**
    - **Radiation damage**

Jet Energy Scale (particle level)

- **Channels (initial GeV) → particle jets/MET**
  - Correction for detector effects.
    - **Non-linear calorimeter response** **- e/h >> 1.0**
    - **B-field effect** **- 4 Tesla**
    - **Cracks / dead material**
    - **Pile-up** **- 17 min.bias/beam crossing**

Jet Energy Scale (parton level)

- **Particle jets/MET → partons or physics observable,**
  e.g. Jet E_T spectrum, di-jet mass, etc.
  - Correction for physics effects.
    - **Fragmentation**
    - **Initial & final state radiation**
    - **…**

Tools

A) Collimated Co^{60} gamma source
- every tile: light yield
- during construction
  - all tiles (100k tiles)

B) Moving Co^{60} gamma source:
- full chain: gain
- during CMS-open (manual)
  - all tiles
- during off beam time (remote)
  - tiles in layer 0 & 9

C) UV Laser:
- full chain: timing, gain-change
- during off beam time
  - tiles in layer 0 & 9
  - all RBX (readout box)

D) Blue LED:
- timing, gain change
- during the off beam time
  - all RBX (readout box)

E) Test beam
- normalization between
  - GeV vs. ADC vs. A,B,C,D
- ratios: elec/pion, muon/pion
- before assembly
  - a few wedges

F) Monte Carlo
- from testbeam to CMS

G) Physics events
- inter channel calibration
  - min. bias events
  - Isolated muons
  - Isolated charged hadrons
- jet energy scale
  - photon+jet balancing
  - Z+jet balancing
  - di-jets balancing
  - di-jet mass
    - W->jj in top decay
  - + ???

Calibration Scenario (HB/HE)

(same to HF)

1) During manufacturing: (done)

- collimated γ source — all tiles
- moving source: — all tiles

2.1) After HB/HE assembled: 2002-2007

- moving γ source: — all tiles / 2 layer
- UV laser: — 2 layers/wedge

2.2) With sample modules: 2002-2006

- test beam: — a few wedges.

→ Absolute calib. Accuracy of 2% for single particle

3) Before closing the CMS: 2006/2007

- moving γ source: — all tiles
- UV laser & blue LED: — all RBX

4) Beam off times: 2007-

- moving γ source: — 2layer/wedge
- UV laser: — 2 laer/wedge
- UV laser & blue LED: — all RBX

→ Monitor for change with time Accuracy < 1%

once/month (?)

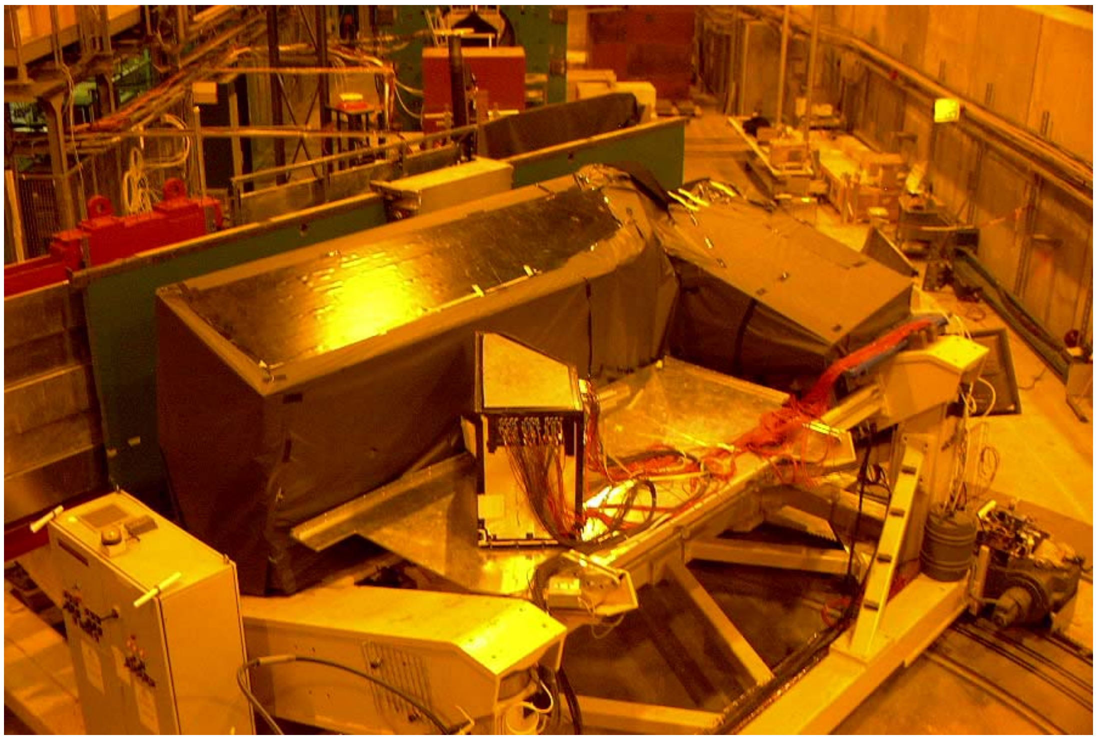
a few times/day (?)

5) Beam on (in situ): 2007-

- physics events — ECAL+HCAL

Test Beam: 2002-2003

2 HB production wedges, 1 HE prototype wedge
HO layers on a movable table at CERN H2 beam line.



2002/03: pi- 20-300GeV, e- 20-100GeV, mu- 225GeV
2004: low energy beam (pi 2-15GeV)

Goal:

- Test the integrated system with production modules

- Verify γ source calibration
- Source/ADC vs. GeV/ADC

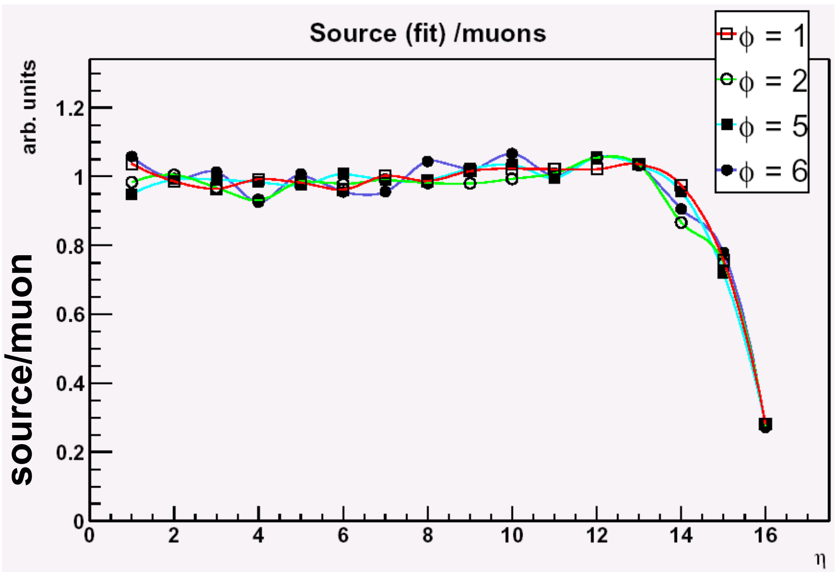
- Operate all calibration tools and look for improvement.

- measure basic parameters for MC, e.g.
    - pulse shape
    - signal timing
    - attenuation
    - noise
    - gaps between modules
    - resolution and linearity

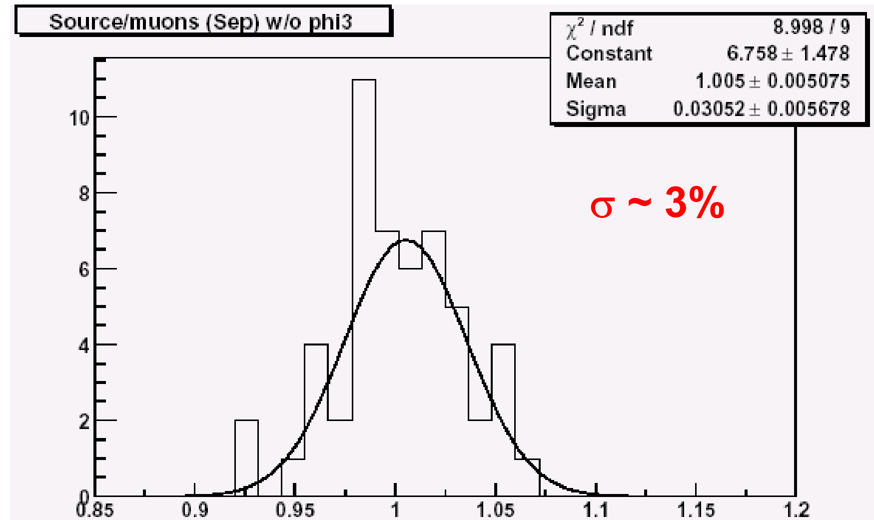
All achieved !

Inter Channel Calibration

γ source vs. muon signal (HB)



η tower #

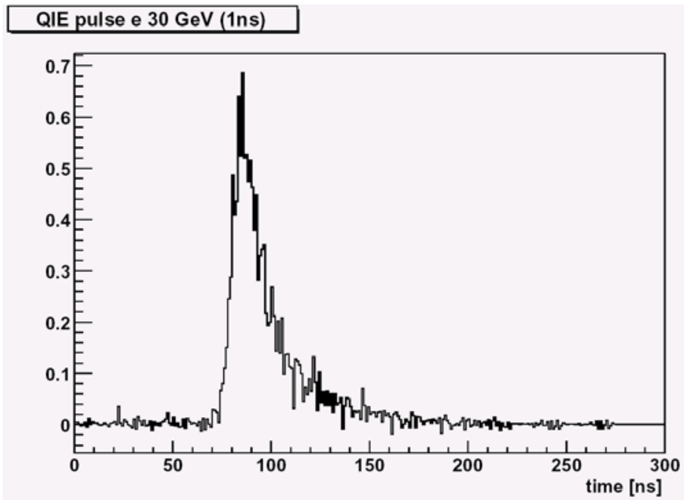


source/muon

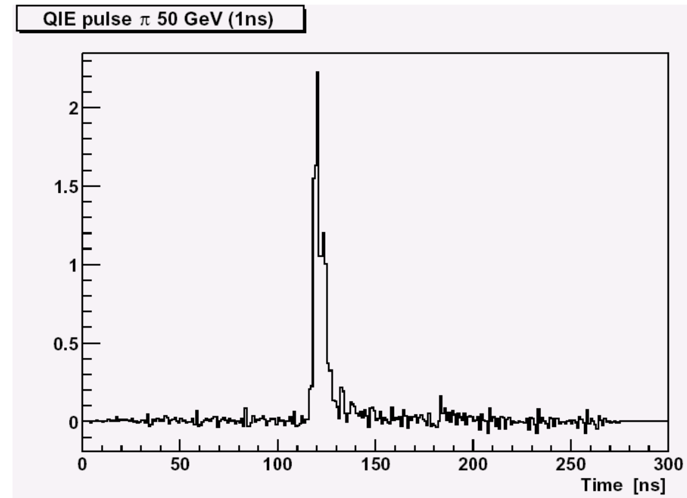
- Source calibration: better than 3%
- Muon signal: useful for calibration, if rate is large enough.

HCAL Pulse

HB/HE

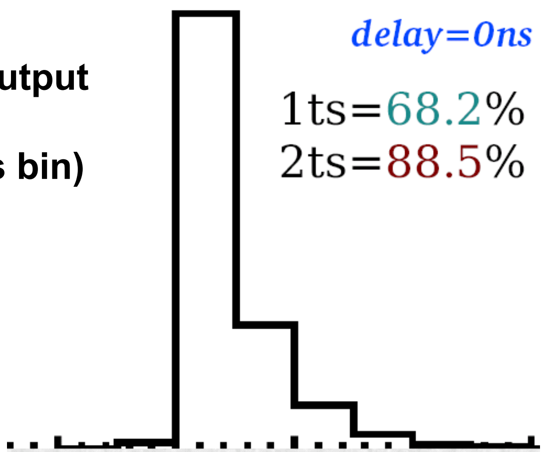


HF



QIE output

(25ns bin)



HF pulse is fast. → in-time pile-up only.

HB/HE → both out and in-time pile-up.

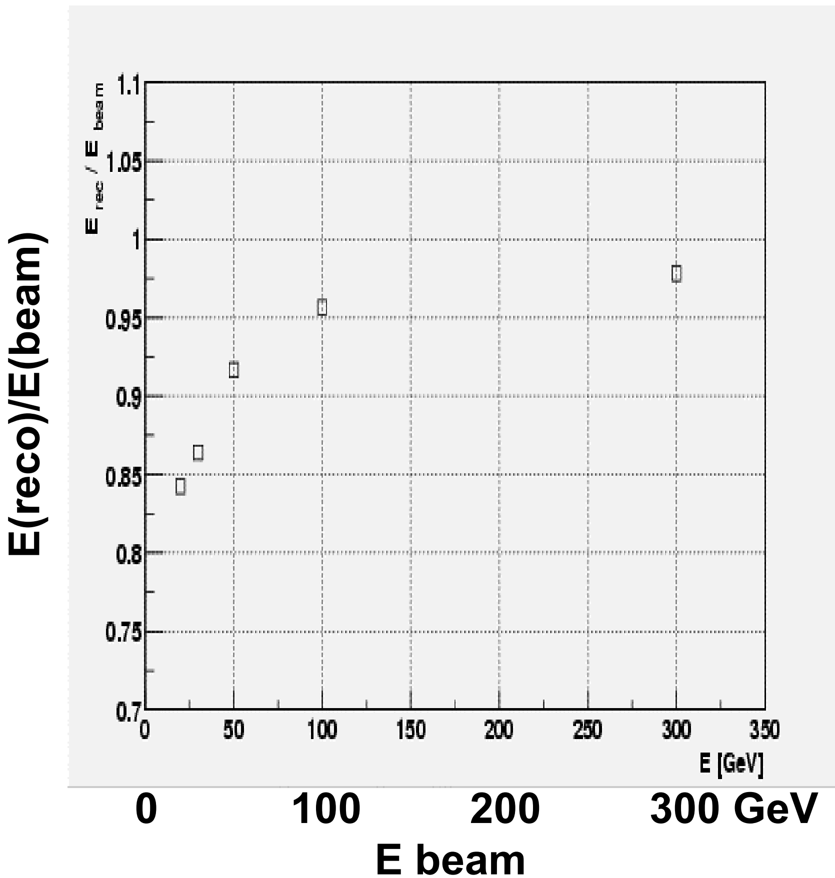
Need algorithms for energy correction/subtraction for pile-up!

So far, 3 methods for pile-up energy subtraction:

a) using average pile-up energy for given luminosity
b) assuming ϕ-symmetry in each event.
c) using jet shape.

From Test Beam to CMS

2002 H2 Teast Beam Data



(Lowest data point 20GeV)

Test beam data with gamma source calibration will give energy scale at the begging of the CMS run.

But it has limitation-

Test beam environment does not have B-field and Tracker material.

→ We use MC.

In order to verify MC, we need data points below 15GeV.

→ TB2004 for 2-15GeV.

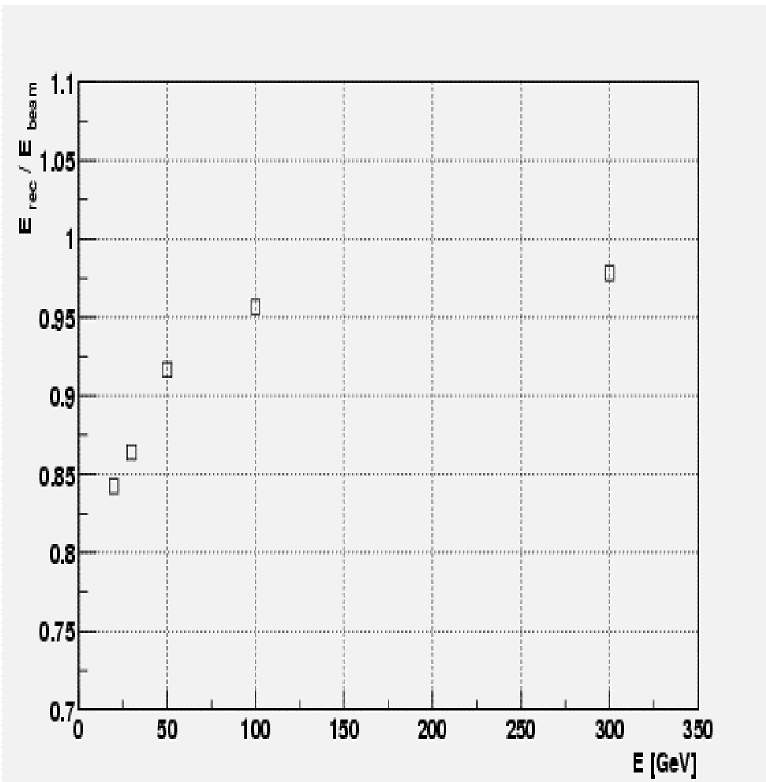
>> need "in situ" calibration

Pion Response: Linearity

ECAL+HCAL: Non compensating calorimeter

2002 H2 Teast Beam Data

E(reco)/E(beam)

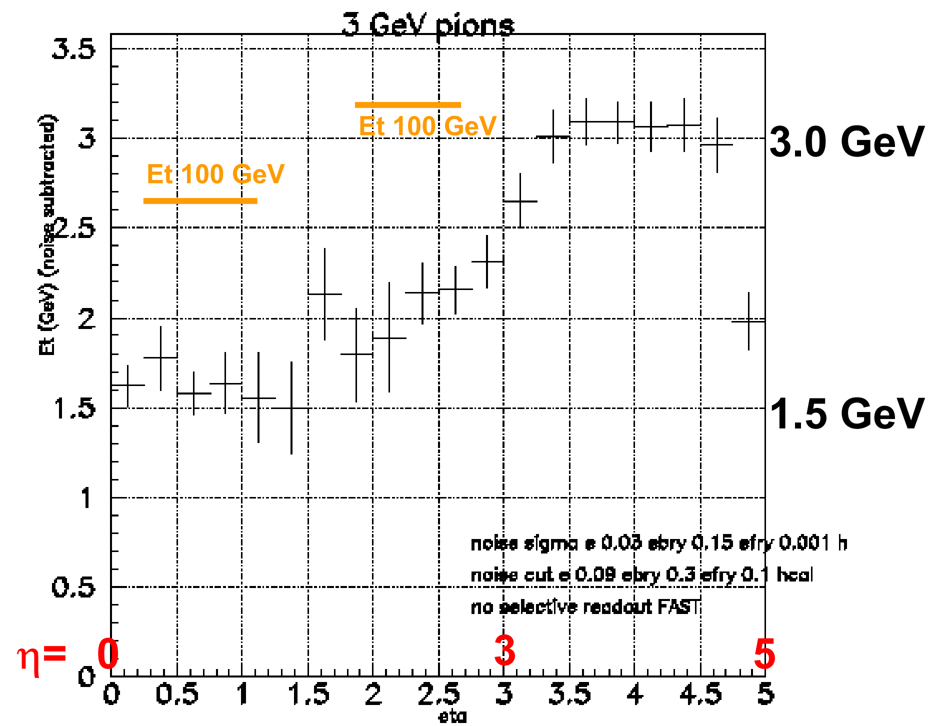


0 100 200 300 GeV

E beam

CMS GEANT3 Simulation

P_T=3 GeV pion in $0<|\eta|<5$

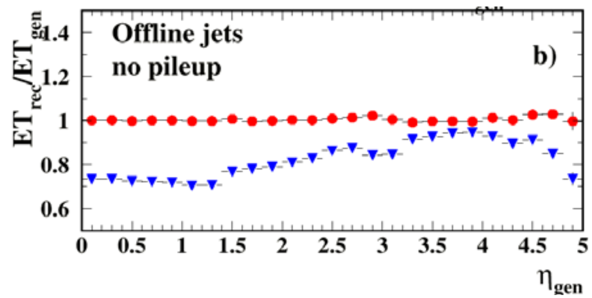


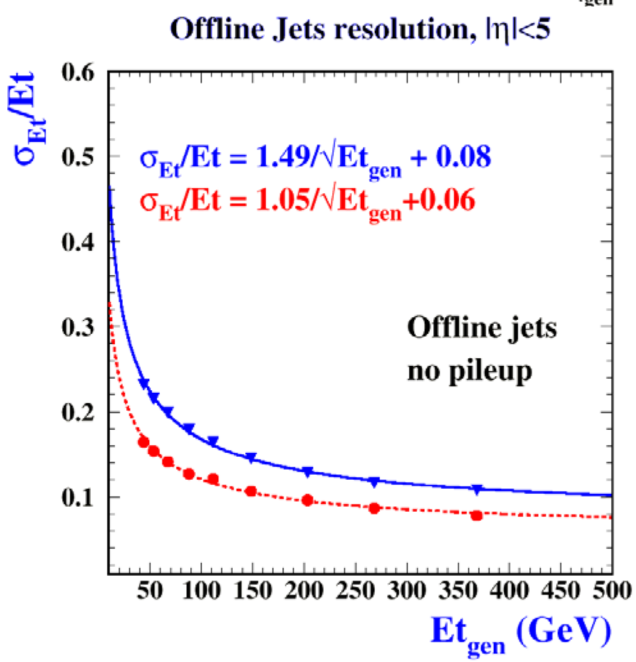
P= 3 7 30 82 227 GeV

Jet Energy – Cone $\Delta R<0.5$

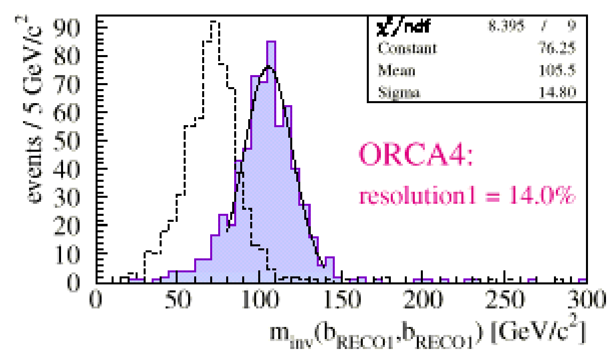
Map of response in E_T-η: $E_T(\text{corr}) = a + b \times E_T(\text{raw}) + c \times E_T(\text{raw})^2$

a,b,c depends on E_T and η





M(bb) in ttH



Jet energy correction

without: 19%

with: 14%

→ Level 1 trigger, HLT trigger, offline

Jet Energy – Using Tracks (E-Flow)

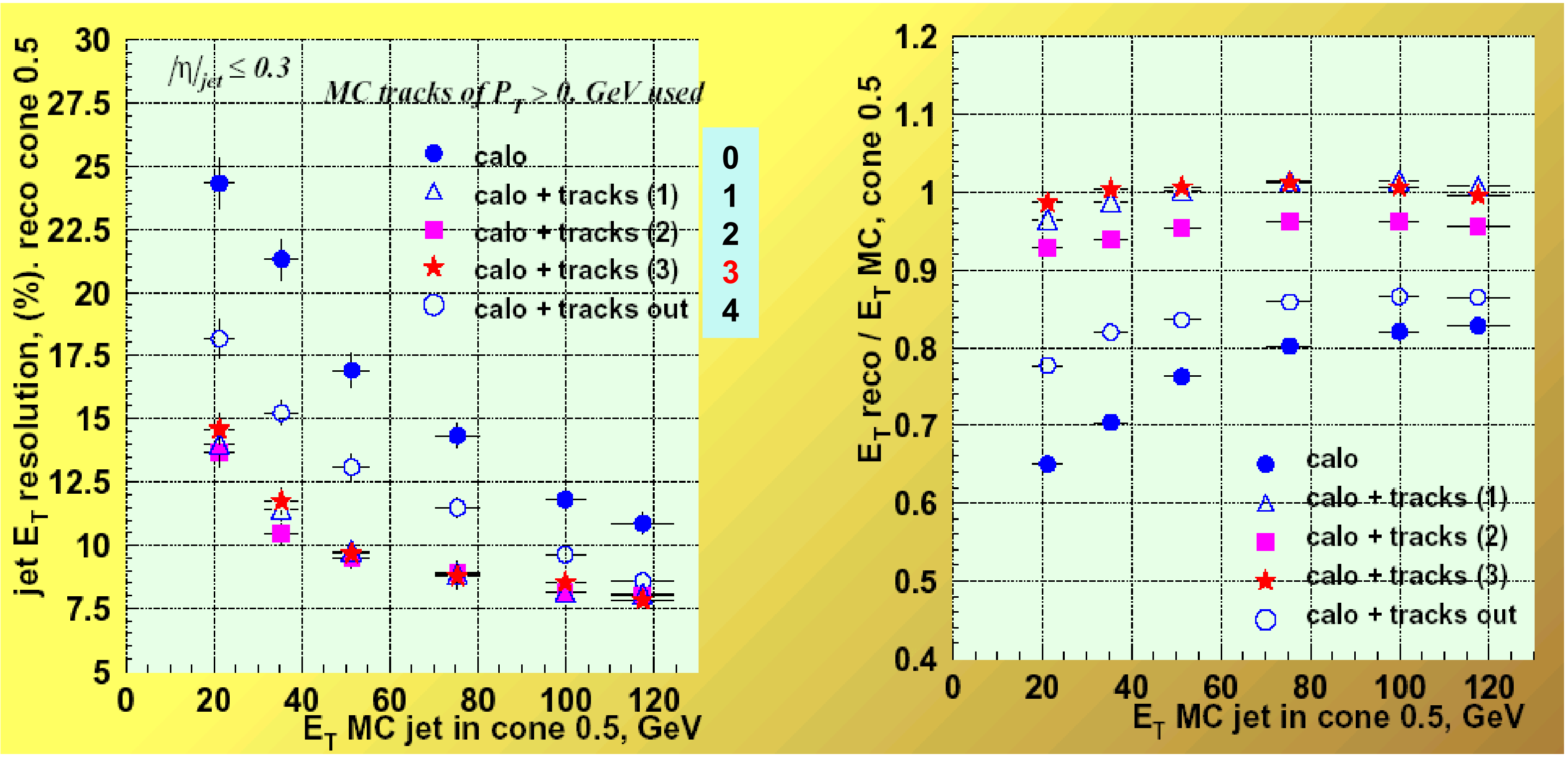
$E = EC(e/\gamma) + (EC+HC)(\text{neutral.h}) + \text{Tracks}(\text{charged.h})$

Resolution

20GeV 24% → 14%
100GeV 12% → 8%

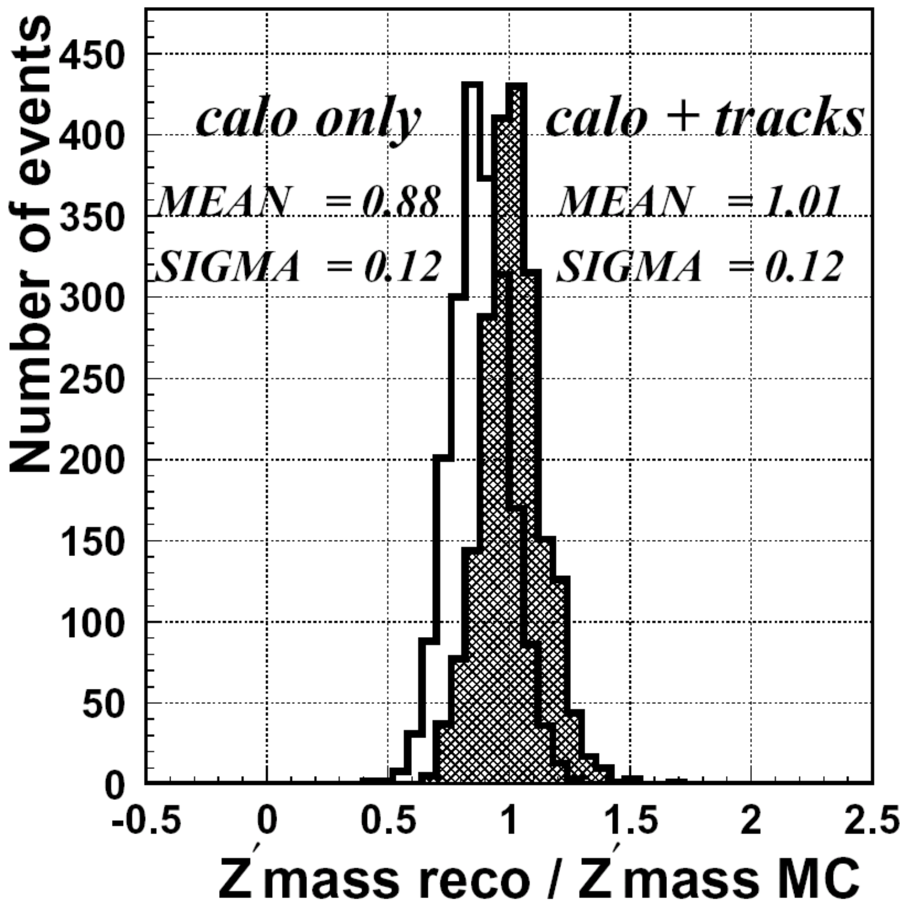
E_T Scale

δ < 2% in 20-120GeV



0: no correction (calorimeter only) 1: calo response - simple average 2: calo response – library
3: full correction (library of response, track-cluster match, out-of-cone tracks)
4 out-of-cone tracks correction only

Z'(120) → j + j with E-Flow



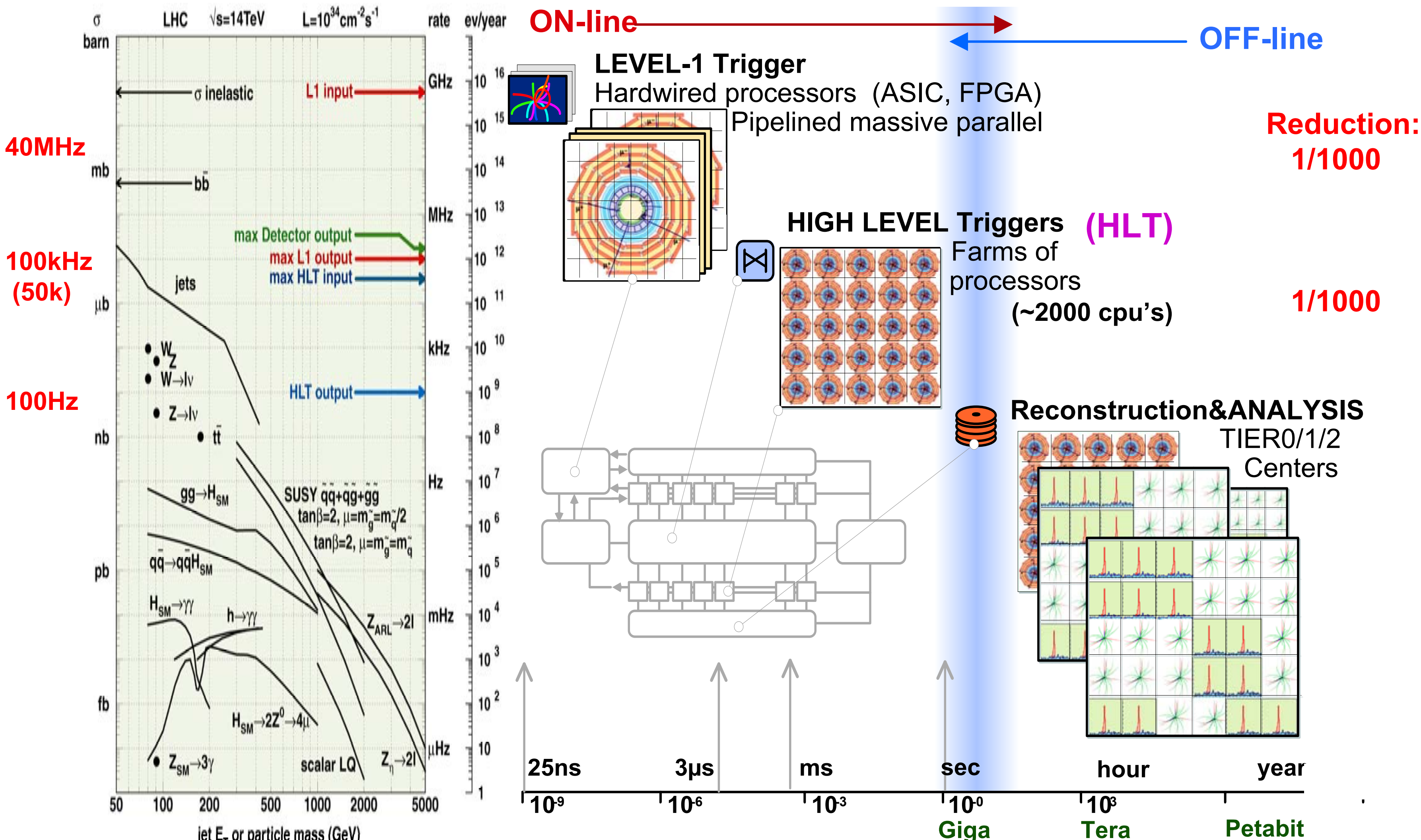
The E-flow algorithm restores the energy scale.

The algorithm requires a good library of the calorimeter response to charged hadrons.

We build the library using Monte Carlo and isolated charged particles (in situ).

→ MC: V.Daniel Elvira
→ In-Situ: following slides.

Physics Selection



We plan to use HLT farm to select calibration events and minimize the data volume.

L1 for Low Luminosity
2 x 10^{33} cm^{-2} s^{-1}

Trigger	*Threshold (GeV or GeV/c)*	*Rate (kHz)*	*Cumulative Rate (kHz)*
Isolated e/γ	29	3.3	3.3
Di-e/γ	17	1.3	4.3
Isolated muon	14	2.7	7.0
Di-muon	3	0.9	7.9
Single tau-jet	86	2.2	10.1
Di-tau-jet	59	1.0	10.9
1-jet, 3-jet, 4-jet	177, 86, 70	3.0	12.5
Jet*E_T^{miss}	88*46	2.3	14.3
Electron*jet	21*45	0.8	15.1
Min-bias		0.9	16.0
TOTAL			**16.0**

A prototype L1 table for 50kHz system with x3 safety factor.

HLT for Low Luminosity
$2x10^{33}$ $cm^{-2}s^{-1}$

Results from full detector and trigger simulation – 7M events used in 2001-02.

Trigger	Threshold (GeV or GeV/c)	Rate (Hz)	Cuml. rate (Hz)
Inclusive electron	29	33	33
Di-electron	17	1	34
Inclusive photon	→ 80	4	38
Di-photon	40, 25	5	43
Inclusive muon	→ 19	25	68
Di-muon	→ 7	4	72
Inclusive tau-jet	→ 86	3	75
Di-tau-jet	59	1	76
1-jet * E_T^{miss}	180 * 123	5	81
1-jet OR 3-jet OR 4-jet	657, 247, 113	9	89
Electron * jet	19 * 45	2	90
Inclusive b-jet	237	5	95
Calibration etc	→	10	105
TOTAL			**105**

CMS DAQ TDR, Dec. 2002 (CERN/LHCC 2002-26)

In-situ calibration (I)

Zero bias / Min-bias trigger

- Estimation of pile-up energy
- Normalization in each η-ring.
- Isolated low E_T charged tracks.

QCD Jet Trigger (Pre-scaled)

- Normalization in each h-ring.
- Normalization at the HB/HE/HF boundary.
- Test uniformity over full h-range.
- Isolated charged tracks

Tau Trigger

- isolated high E_T charged tracks

Muon trigger

- W → mn, Z→ mm

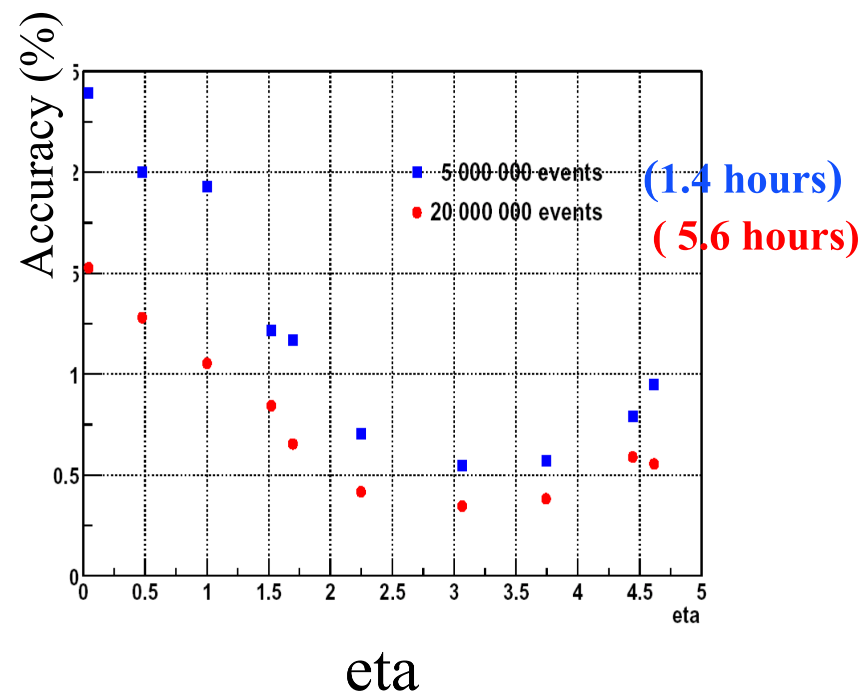
  ~ 10Hz at low luminosity $2x10^{33}$ cm^{-2} s^{-1} .

Isolated Charged Tracks

0.2 track/event for P_T=1-5 GeV/c.

Need special treatment in HLT for high statistics?

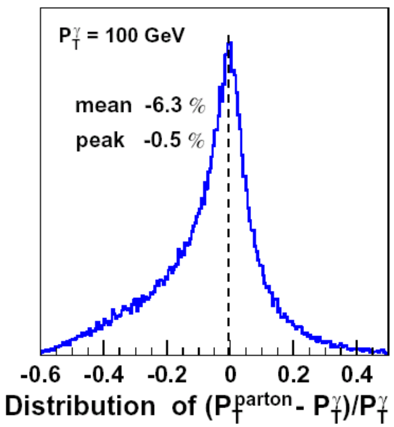
Using ϕ-symmetry in min-bias events



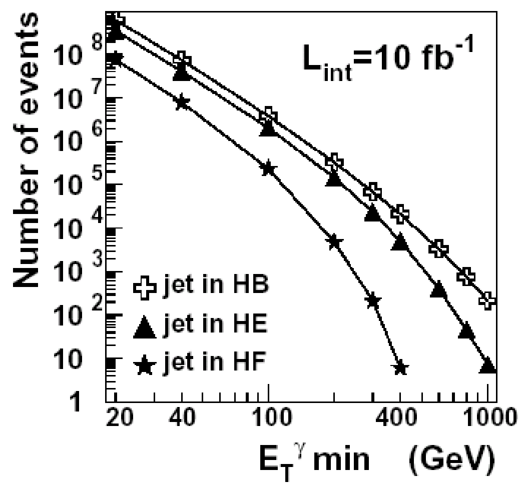
Process min-bias events in the HLT farm at 1kHz and send “histograms” to tape.

In-situ Calibration (II)
γ + j / Z + j

γ + jet E_T balance



γ+jet events, $|\eta^{\gamma}|$ <2.5, $|\eta^{jet}|$ <4.5, (PYTHIA 6.2)

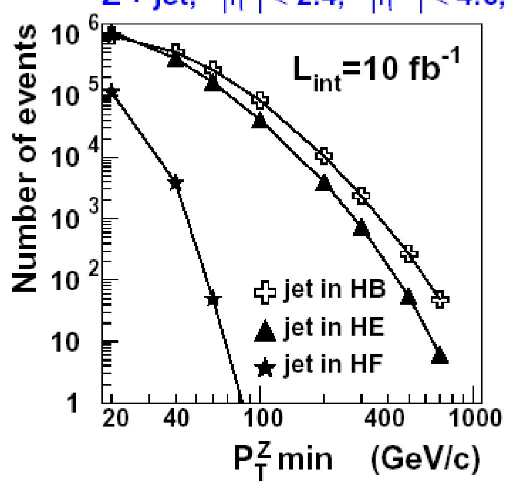


Statistics possibility

jet for calib-ration	frac-tion (%)	max of ETjet (GeV)
any jet	100	~800
q-jet	90	~800
b-jet	5	~400

Z + jet E_T balance

Z + jet, $|\eta^{\mu}| < 2.4$, $|\eta^{jet}| < 4.5$, $|M_{\mu+\mu-} - M_Z| < 10$ GeV/c^2 (PYTHIA 6.2)



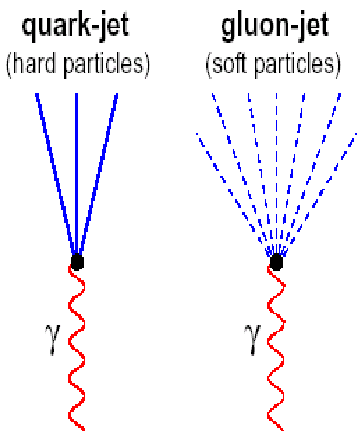
Statistics possibility

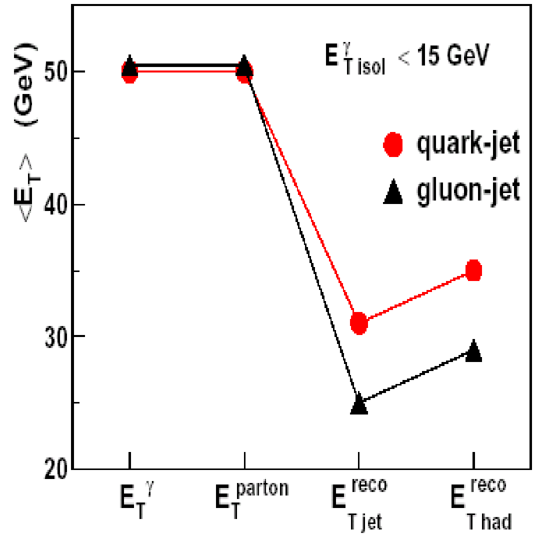
jet for calib-ration	frac-tion (%)	max of ETjet (GeV)
any jet	100	~400
q-jet	80	~400
b-jet	5	~200

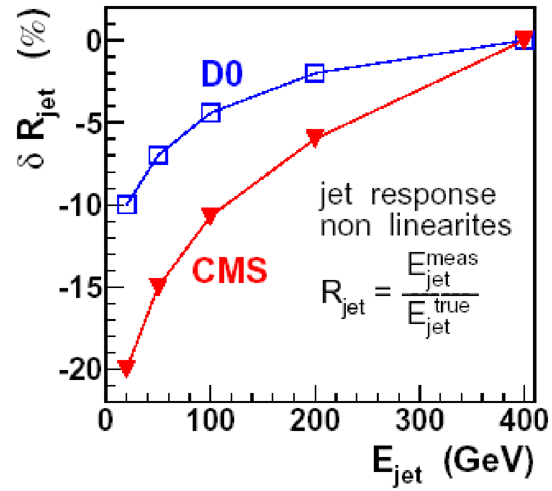
Lower rate than γ+j, but less background.

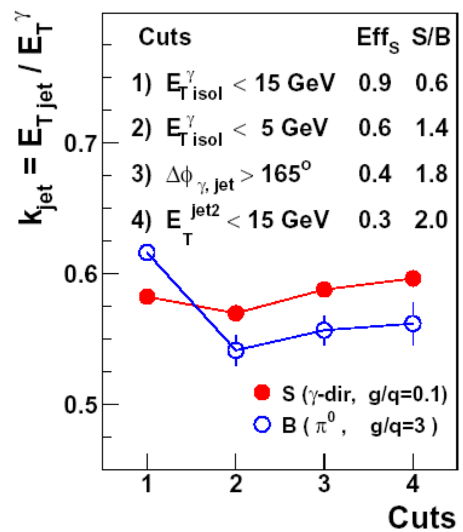
quark-jet and gluon-jet in γ + jet

γ+jet, E_T^{γ} = 40-100 GeV, 0.5 cone jet, barrel, low-lumi, $3\sigma E_{niose}$ cut on cell (ORCA 631, PYTHIA 6.2)









q-jets
S 90%
B 30%

Non linearities of calorimeter $\Rightarrow$ $k^{g}_{jet} < k^{q}_{jet}$

$$k_{jet} = E^{\ reco}_{T\ jet} \,/\, E_T^{\ \gamma}$$

HLT for calibration: γ + jet

γ+j requires a dedicated HLT.

γ + jet trigger

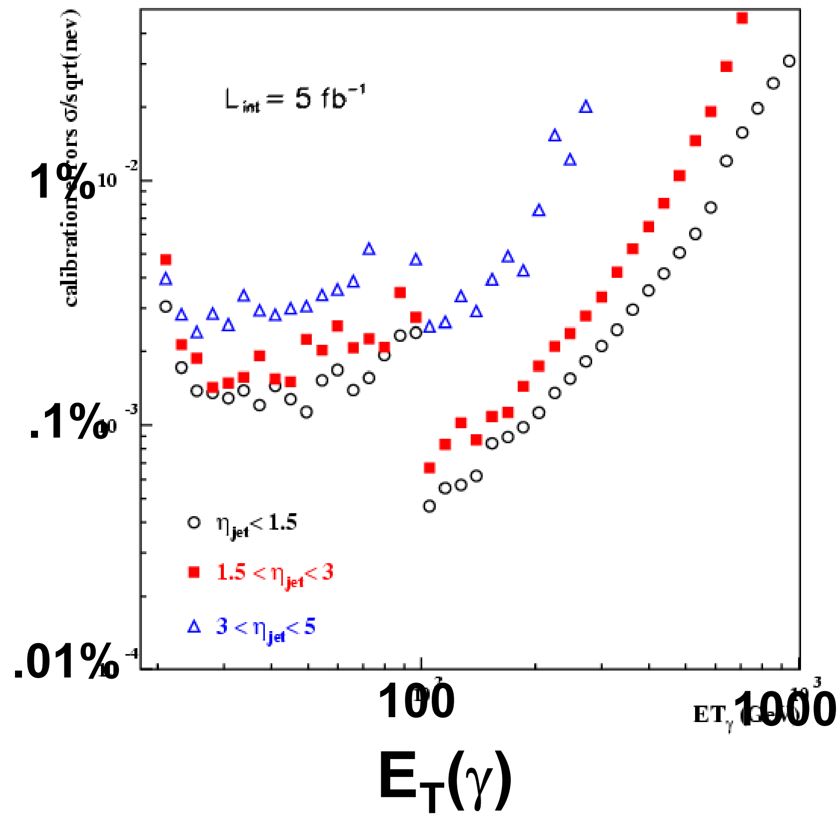
For E_T>80GeV:

- HLT single photon

For E_T<80GeV

- L1 e/gamma (ET>23GeV)
- very tight γ isolation with pixel and ECAL
- pre-scale

Statistical error after 3mo. running with 1Hz at 2E33



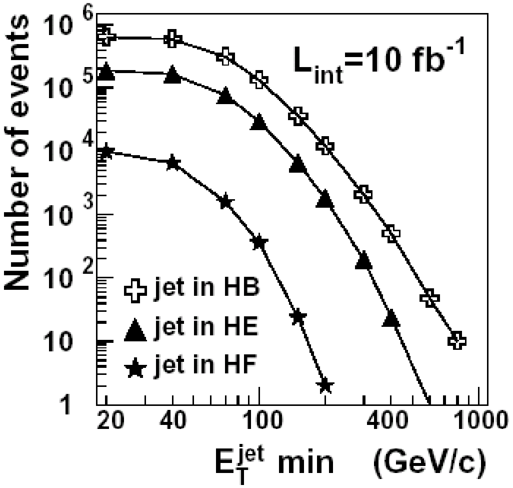
No tracker in front of HF.

→ γ+j & Z+j are major tool for calibration and monitoring of HF.

In-situ Calibration (III)

W→ j + j form top decay

High rate to apply double b-tag.



$t\bar{t} \to Wb\,Wb \to l\nu b\,qqb$ (q = u, d, s, c)

E_T^l>20 GeV, E_T^{miss}>20 GeV, E_T^b>40 GeV

$|\eta^{l/b}| < 2.5$, $|\eta^q| < 4.5$ (PYTHIA 6.2)

Statistics possibility

jet for calib-ration	frac-tion (%)	max of ETjet (GeV)
q-jet	100	~300

DC 04 Sample available for calibration study (JetMET group)

γ + jet	40-200GeV	0.5M events
Z + jet	0-2.2 TeV	1.6M
W + jet	0-2.2 TeV	3.2M
Tt	W→all	3.5M
Tt	W→lν	1.0M
QCD jets	0-4.0 TeV	3.2M

Summary

- Radioactive source and test beam give inter channel calibration and HCAL energy scale in GeV. (~2% initially.)
- We measured HCAL parameters in testbeam 2002-2003 using production modules. We take data with pion 2-15GeV this year.
- Radioactive source, laser and several physics channels will track changes of HCAL response over years. (better than 1%.)
- Studies on calibration with several physics channels are in progress.
- So far, our calibration studies emphasized more on detector effects. We need to move to calibration/correction scheme for final physics observable.
- We need to pick right physics bench marks to develop algorithms for calibration/correction, covering

  15 GeV – 4 TeV jet E_T || 0 – 20 (or more) interactions per beam
  1 – 10 (or more) jets || boosted di-jet system, etc…

- Need a lot more work for MET.

We need all tools and triggers in place by day one in 2007.
Input from Tevatron experience is critical!